γ-ray Burst Remnants: How can we find them?

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1 Introduction

By now there is substantial evidence that Gamma-Ray Bursts (GRBs) originate at cosmological distances from very powerful explosions. The interaction between a GRB and its surrounding environment has dramatic consequences on the environment itself. At early times, the strong X-ray UV afterglow flux photoionizes the medium on distance scales on the order of 100 pc [7], destroys dust [10], creates photoionization edges [6]. These are short-term effects, that occur while the afterglow is propagating into the medium.

In this contribution, I discuss the *long-term* effects resulting from the interaction between a GRB and its environment. In particular, in §2, I discuss signatures of the emission spectrum produced while the heated and ionized gas slowly cools and recombines. Besides photoionizing the medium with its afterglow, a GRB explosion drives a blast wave which is expected to have a very long lifetime. In §3, I discuss possible candidates for such GRB remnants in our own and in nearby galaxies, and ways to distinguish them from remnants due to other phenomena, such as multiple supernova (SN) explosions.

2 Spectral signatures of a cooling GRB remnant

Let us consider a GRB afterglow source which turns on at time $t = 0$ and illuminates a stationary ambient medium of uniform density n, initially neutral and in thermodynamic equilibrium. Perna, Raymond & Loeb ([8]) computed, as a function of position and time, the temperature of the plasma, the ionization state of the elements, and the emission in the most important lines. The gas is heated up to $T \sim 10^5$ K, and cools over a time $t \sim 10^5 (T/10^5\mathrm{K})/(n_e/1\ \mathrm{cm}^{-3})$ yr. This time, combined with the GRB rate $\sim (10^{6-7} f_b\ \mathrm{yr})^{-1}$ per galaxy [11] ($f_b \le 1$ is the beaming factor), implies that in every galaxy there is a non-negligible probability of finding an ionized GRB remnant at any given time. In order to identify cooling GRB remnants and distinguish them from other emitting regions, such as SN remnants, HII regions, etc., line diagnostics are extremely useful. Fig. 1 (from [8]) shows some line ratios which are very sensitive to the type of mechanism by which the gas has been ionized. For a cooling GRB remnant, they reach much higher values than in shock heated gas and HII regions. For example, the ratios [O III] $\lambda5007/\mathrm{H}\beta$ and [O II] $\lambda3727/\mathrm{H}\beta$ are typically smaller than ~ 5 in shock heated gas, while He II $\lambda4686/\mathrm{H}\beta$ is on the order of a few

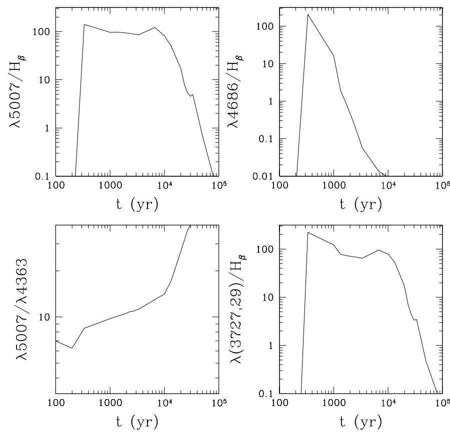

Fig. 1. Some line diagnostics of a cooling GRB remnant of energy 10^{52} ergs in a medium of density 1 cm^{-3}.

tenths. Here, they can all be as high as ~ 100. This is a consequence of having a huge mass of gas which is suddenly photoionized and then let cool. Besides line diagnostics, cooling GRB remnants can also be identified as they are center-filled with high ionization lines, and limb-brightened with low-ionization lines [8]. The non-relativistic blast wave might be visible separately, since it does not reach the outer edge of these young photo-ionized remnants. Furthermore, the remnants should show evidence for ionization cones if the prompt or afterglow UV emission from GRBs is beamed. Therefore, their identification could help constrain the degree of beaming of the GRB emission.

3 GRB remnants: hydrodynamic effects

Besides photoionizing the medium with its afterglow, a GRB explosion drives a blast wave into the medium. This will be washed out by interstellar turbulence only after it has slowed down to a velocity of ~ 10 km s^{-1}. For a uniform medium of density n_1 cm^{-3} and an energy of 10^{54} ergs deposited in the gas, this will happen at a radius $R_{\rm kpc} = 0.7\, E_{54}^{0.32} n_1^{-0.36}$ after a time $t = 2.1\,\times\,10^7 E_{54}^{0.32} n_1^{-0.36}$ yr. Given the GRB rate per galaxy [11], one estimates that a few such GRB remnants should be present in every galaxy at any given time. Have we already identified them? Maybe. For several decades, 21 cm surveys of spiral galaxies have revealed the puzzling existence of expanding giant HI supershells [2] whose radii are much larger than those of ordinary SN remnants and often exceed ~ 1 kpc. Their estimated ages are in the range 10^6–10^8 years. Whereas small shells of radii $\sim$ 200–400 pc and energies $\leq$ a few $\times 10^{52}$ ergs are often explained as a consequence of the collective action of stellar winds and supernova explosions originating from OB star associations [5], the energy source of the largest super-

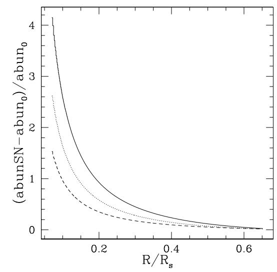

Fig. 2. Metal enhancements for a giant supershell powered by multiple SN explosions.

shells is still a subject of debate. If due to multiple SNe, some of these supershells would require about 10^4 SNe to power them; such large OB associations, even though not impossible, have never been observed in a survey of thousands of HII regions in nearby galaxies [3]. The similarity between the expected properties of GRB remnants and those of HI supershells prompted the suggestion that the energy source of some of these supershells might actually be GRBs [1,4]. This hypothesis could be tested based on the fact that SNe inject metals in the ISM in which they explode. As a result, if a supershell has been powered by multiple SNe, the abundances of some specific metals in its interior should be enhanced with respect to the typical values in the ISM surrounding the shell [9]. Fig. 2 shows the expected enhancements in the abundances of O, Ne, and Si for a supershell of energy $E = 5 \times 10^{53}$ ergs and age $t = 5 \times 10^7$ yr that has been powered by multiple SNe. The enhancements are more pronounced in the inner regions, as most of the extra metals are injected at early times due to the shorter lifetime of the most massive stars. Such peculiar abundances can be probed by measuring ratios between X-ray emission lines of two elements, one of which is more enhanced than the other [9]. Being able to identify which HI supershells have been produced by multiple SNe and which ones by GRBs would help constrain GRB rates and energetics, as well as their location within a galaxy.

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